Faceted Search on Coordinated Tablets and Tabletop: a Comparison

Sven Charleer[1], Joris Klerkx[1], Erik Duval[1], Tinne De Laet[2], Katrien Verbert[1]
[1]Dept. of Computer Science, KU Leuven, Celestijnenlaan 200A, B-3001 Leuven, Belgium
[2]Tutorial Services Engineering Science, KU Leuven, Celestijnenlaan 200I, B-3001 Leuven, Belgium
firstname.lastname@kuleuven.be

ABSTRACT
Large interactive displays and surfaces are useful modalities for visualizing big multi-dimensional data sets. They can offer simultaneous views on different facets of the data which lead to an efficient and effective environment for data exploration and analysis. While every data analyst and enthusiast can benefit from these advantages, large interactive systems are not yet available to everyone. Meanwhile, tablets have become ubiquitous and relatively cheap. Combining multiple tablets to replicate a single, large display has therefore become an affordable option. This paper compares the difference in search performance and user perception of a faceted search system for Cultural Heritage data on a single large interactive tabletop with a system composed of multiple coordinated tablet devices. We conclude that, while users generally prefer the tabletop system, there is no negative impact on search performance using tablets. This makes coordinated tablets a viable and portable solution in the absence of interactive tabletops.

ACM Classification Keywords
H.5.2. User Interfaces: Graphical user interfaces (GUI)

Author Keywords
Faceted search; Cross-device applications; User perception; Touch devices; Interactive surfaces;

INTRODUCTION
Faceted search or faceted navigation systems allow exploration of a dataset by applying various data attribute filters to narrow down the information [28]. Visualizing these filters can further improve user experience by helping the user create complex queries across multiple data dimensions [8, 27], reduce trial-and-error [2], and retain a sense of context [9]. Combined with Coordinated Multiple View (CMV) systems, it provides different perspectives on multi-dimensional faceted data simultaneously, helping users understand the data better, and find correlations and patterns [22]. Faceted search also causes fewer disruptions due to view switching, as views of all dimensions can remain visible to help maintain a better mental map [18]. Users can zoom in on potentially more relevant data and continuously keep an overview of how additional search filters restrict the remaining number of objects in the data [6].

The scalability of this solution is mainly limited to screen size and resolution. Large displays enable large quantities of information to be visualized at once, such as high-resolution displays [21], large wall displays [7, 23, 26, 27], and large interactive tabletops [16]. These systems are of great benefit to researchers, but are not always available to them.

While exploring large multi-dimensional data on a tablet [14] can be effective, its small screen size lacks the aforementioned benefits when visualizing many data dimensions at once. With tablets becoming ubiquitous, combining multiple devices to replicate a single, large faceted search interface becomes a more feasible scenario [19]. This work investigates if there is a measurable impact on search performance and user perception when distributing multiple search facets across various devices.

An extra challenge when distributing facets across devices is the visual field discontiguity [20], caused by the tablet bezel and possible physical distance between the devices. Literature shows that bezels can have a very low impact on performance, depending on the task. Wallace et al. [30] found that bezels have no negative impact on visual search performance on large wall displays. Rashid et al. [20] report that bezels only cause small performance overhead for visual attention switching, while discontinuity of the visual representation (e.g. by splitting objects across multiple screens) does impact performance [3]. Hutchings et al. [13] report a negative impact on movement time and accuracy when users navigate a mouse cursor across gaps between screens. We focus on faceted search CMV systems using touch interaction, where each view on the data is already virtually separated and the user directly interacts with each view. As there is no spatial (virtual) continuity between these different views, we hypothesise that moving each view to a separate device will have no effect on the user search performance and perception of the user, making multiple mobile tablets a valuable alternative to large interactive displays.

After a short introduction of the faceted search system and the experiment setup, we will present the evaluation results. We briefly discuss the limitations of the experiment and elaborate on our findings.

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EXPERIMENT SETUP

The main focus of our experiment is to observe the difference in user search performance and user perception between a single and multi-device faceted search CMV system with touch input. Towards that end, we compare a large custom-built interactive tabletop where all views are located on the same physical screen with four coordinated tablets each displaying a single facet view. We focus on following research questions:

- RQ1: Is there a measurable difference in user search performance on coordinated tablets versus large display faceted search CMV systems?
- RQ2: Is there a difference in user's perceived experience of the coordinated tablets versus large display faceted search CMV systems?

We first introduce the device setup and the application developed for our experiment. Then we explain the details of the experiment.

Device Setup

The device for the single screen setup is a large 42" custom-built interactive tabletop with multi-touch capabilities running at a 1920x1080 resolution. The multiple screen setup consists of four 2048x1536 resolution tablets (three iPads Air 2 and one iPad Mini 2). The tabletop displays four facet views simultaneously (see Figure 1). The tablet environment replicates this setup through four tablets each displaying one of four views (see Figure 2).

Visual attention switching can be affected by different depths at which multiple screens are positioned [20]. The tablets are positioned on a flat table, eliminating this effect by matching the tabletop setup. Both systems were set up at a similar height, requiring the user to stand up. The views layout on the tabletop was identical to the layout of the multi-device setup.

Newspaper Search Environment Application

Certain Cultural Heritage platforms such as Europeana provide APIs [1] and tools [10, 24, 29] for both enthusiasts and Digital Humanities (DH) researchers to explore this rich multi-dimensional data. To increase the ecological validity of our results, we developed a faceted search environment on top of a subset of newspaper data from Europeana (search result for "Einstein": 8681 digitized newspapers, years 1850-1949, including OCR text and structured meta-data), allowing DH researchers to explore the dataset with the visual information-seeking mantra of Shneiderman [25]: "overview first, zoom and filter, then details-on-demand". Indeed, researchers can start by taking a broad view of the data to orient themselves into the current dataset. Further exploration of the dataset is possible by manipulating the following widgets (see Figure 1): a map to select countries of newspaper origin (A), a time-line widget to select years of publications (B), a list of newspaper titles and their number of issues (C), and the resulting list of issues (D).

The widgets are part of a modular web application that facilitates different configurations built with Processing.js, HTML and CSS. All widgets can be presented on one device (see Figure 1), spread across multiple devices (see Figure 2) or a combination of both. A Node.js server application handles the coordination between all widgets through Socket.IO. TUIO.js handles the touches for the tabletop application (see Figure 3). Each visualization widget follows the direct touch interaction approach to modify the selections.

All widgets operate as coordinated views. Filtering a facet on one widget affects the data of the others. For example, highlighting Germany in the country widget limits the other widgets to German data. The country widget data is only affected by the selected year range and newspapers. Every filter activity is logged with a time-stamp for post-analysis of the data. For the purpose of this experiment, the subset of newspaper data is stored in a MongoDB database.

Evaluation Setup

We followed a within-subject experiment design, with the order of systems (single or multi-display system) counterbalanced. Participants performed two sets of five tasks on both the single screen and multi-screen setup. Before each set of tasks, the current system was explained to the participant, after which she or he received hands-on time until the participant felt familiar enough to proceed to the tasks. This was followed by a questionnaire on user perception, a System Usability Scale [4] questionnaire per system, and a semi-structured interview.

Tasks were designed to have the user interact with and explore all filter widgets during the course of the evaluation, and include temporal, location, newspaper title and issue questions. The sets of tasks were two variations of the following questions:

1. Which French newspaper published most between 1891 and 1914?
2. Which country published most newspapers between 1850 and 1887?
3. Which is Poland's oldest newspaper?
4. How many different newspapers does Poland have?
5. In the period of 1880 and 1925, how many issues did the top 3 newspapers of Estonia publish in total?

All filters were reset before each task to create an equal starting point for every time-to-task measurement.

The evaluation comprised 22 users (6 F, mean age: 34 years, SD:12), with a varied background in the use of tablets and tabletops (see Figure 4). Participants who were not familiar with tabletop devices all stated they felt very comfortable interacting with the device. Furthermore, no participants in this evaluation were familiar with the dataset at hand nor had they any experience with DH research. Due to bugs discovered and fixed early in the evaluation, the time-to-task results of the first two participants were removed, leaving 20 cases.

EVALUATION RESULTS

To investigate RQ1, we look at both time-to-task and search path length. Time-to-task gives an overall result of participant speed while performing the task. The search path length lets

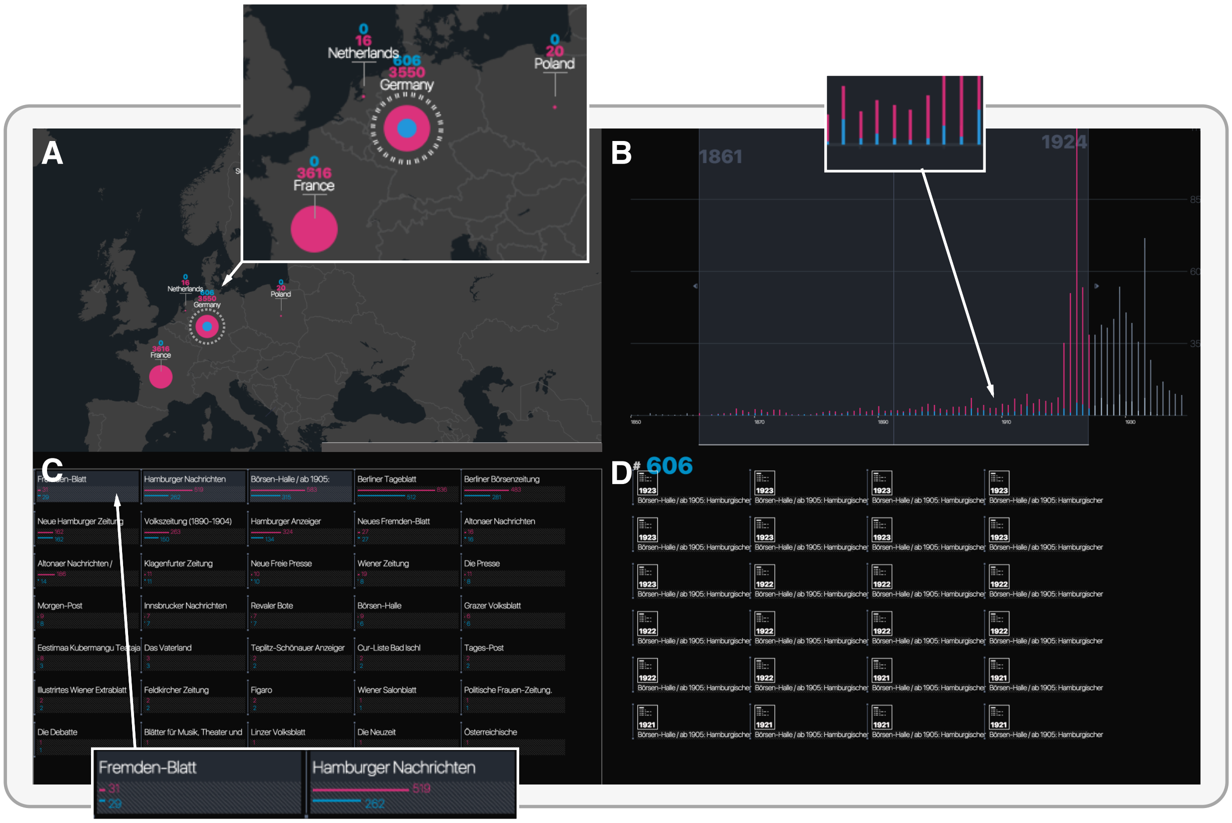

Figure 1. The newspaper data can be filtered through four facet widgets displayed on a single large tabletop. In this example, Germany is selected in A. The time range 1861 to 1924 is set in B. Three newspapers are chosen in C. D visualises the resulting set of newspaper issues. Every view is updated with the selections of the others e.g. the inner (blue) circle of Germany (A) represents the 606 German issues matching the timeline 1861-1924 (B) and the newspapers Fremden-Blatt, Hamburger Nachrichten and Borsen-Halle (C).

us compare the systems at a more detailed level, i.e. time per step and number of steps.

Time to Task

Figure 5 shows the completion time per question for each setup. Each participant arrived to the correct answer. The difference in time for each task reflects the difficulty of each question. The box-plots show a slight trend for better time-to-task results for tasks 1, 2 and 5, with a lower average time-to-task and lower 25% and 75% quartiles. Task 3 shows a smaller mid-spread for the tablets with a slightly higher median. The 25% and 75% quartile of task 4 are lower for tabletop. Overall there is no indication of a difference in time-to-task across the two systems.

Search Path Length

We take a deeper look at how this task time is spent on each system and whether there is a difference in the search path length, i.e. the sequence of different filter steps and thus interactions with each facet widget a participant takes. For each task, we logged the number of interaction steps, e.g. selecting a country and thereafter selecting a newspaper title equals two steps of a search path. Selecting time requires two steps, setting a minimum and maximum date. Backtracking due to mistakes (e.g. selecting the wrong country and thus deselecting that country) will add steps to a task.

We analysed the final task (task 5) performed on each system as it required the usage of all visualization widgets. This task required the participants to switch their attention between all devices and is thus affected most by the visual field discontiguity [20]. Task 5 also showed the largest difference in median and distribution shape (see Figure 5). This task required the user to modify the time range, to select the appropriate country and to select three newspaper titles to get the total result of the selection as the answer to the question. This task could be performed in either three steps whereby the participants calculates the total, or a minimum of six steps if the participant selects the three newspaper titles. As mentioned before, correcting mistakes adds additional steps to the search path length.

Figure 6 (top) shows the number of steps the participant performed to complete the 5th task. The participants performed on average 1.2 step less on the tablets than on the tabletop (tabletop: M=10.94, S=D8.13, tablet: M=9.70, SD=4.71). The spread is slightly longer for tablets (1.0 second) and the mid-spread slightly shorter for tablets (0.5 seconds). The time per step on both systems shows little difference (tabletop M=6.41,SD= 3.46 vs M=6.34, SD=2.85), with only a mid-spread difference of 0.64, but a larger spread for the tabletop (see Figure 6, bottom). We believe that these small differ-

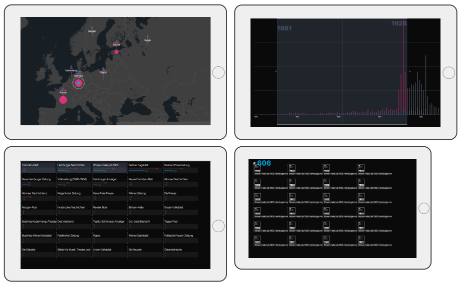

Figure 2. The setup with tablets: each widget is displayed on its own device. The widget layout is identical to the tabletop.

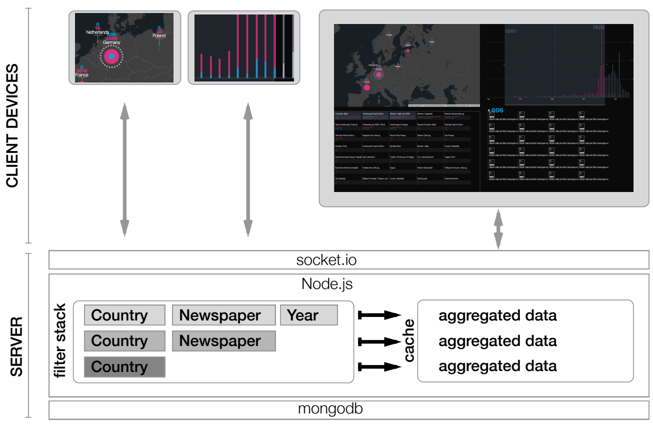

Figure 3. Application architecture: client devices run different layouts of the modular web application and communicate through Socket.IO with the Node.js server. The server stores the filter history and cache.

ences are clear indications that participants do not search less efficiently on the tablets.

User Perception

SUS questionnaires resulted in similar perceived usability for tabletop (M=82.36,SD=11.83) and tablets (M=80.25,SD=12.87). We can therefore conclude that perceived usability is not an issue with either system.

Perceived awareness of changes happening across widgets (e.g. changing time selection affects the three other widgets) rated slightly higher for the tabletop (7-Likert scale, 1-No awareness, 7-Complete awareness; tabletop M=6.1, SD=0.7; tablets M=5.8 , SD=0.9). However, the multiple views caused less confusion on the tablets (7-Likert scale “Causes confusion”, 1-Completely disagree, 7-Complete agree; tabletop M=2.6, SD=1.4; tablets M=2.1 , SD=1.0).

When asked to compare both systems (see Figure 7), there is a small trend towards participants perceiving search performance as better on the tabletop (5-Likert scale, 1-Tablets

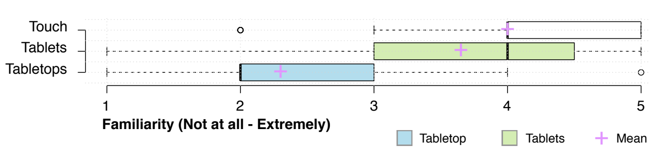

Figure 4. Familiarity with touch interfaces, tablets and interactive tabletops of the participants.

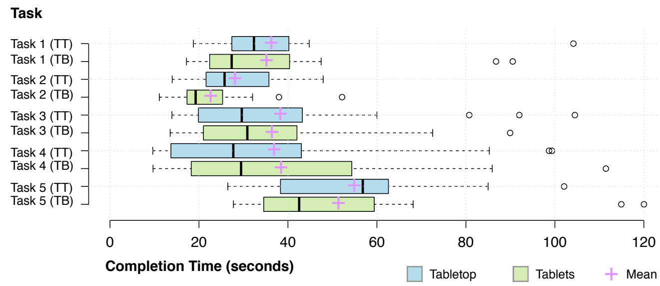

Figure 5. Participants’ time-to-task results per task and setup.

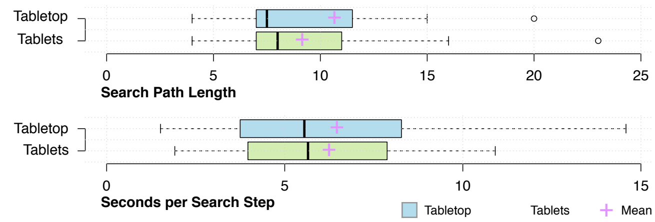

Figure 6. Search path length and seconds per step for task 5.

perform worse, 5-Tablets perform better, M=2.8,SD=0.7). Regarding awareness of the impact of their filter actions across widgets, the tabletop is also perceived as better (M=2.5,SD=0.7). The semi-structured interview revealed all participants but two preferred the tabletop version, with twelve participants indicating a worse sense of overview due to the multiple devices.

Six participants reported the bezels and gaps as the main cause for their negative perception (“The edges disturb when moving my eyes from one view to another”, “It creates more overhead”). These participants suggested that tablets without bezels could improve their search performance and help create a better overview.

Earlier findings have shown that the impact of visual field discontiguity depends on the task [20]. Even though participants had the impression the discontigous setup negatively impacted their sense of overview and performance, no difference was observed in the time-to-task results.

Four participants mentioned advantages for multiple devices as opposed to the tabletop for faceted search (“they facilitate working on individual facets better”, “I am more tempted to focus on one facet”, “I could pick one up to dig deeper in one facet”). Eight participants mentioned portability as another advantage (“I can set this up at home”, “I can move more freely around the workspace”, “I can take this with me”). An-

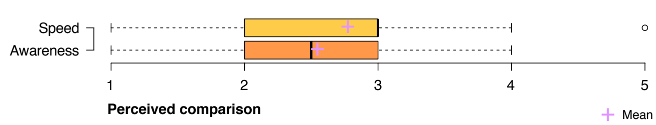

Figure 7. User perceived performance comparison (5-Liker scale, 1-much worse, 5-much better). Speed: I think the tablets version compared to the tabletop regarding speed at which I can solve the tasks performed... Awareness: I think the tablets version compared to the tabletop regarding staying aware of the impact of my actions performed...

other participant added: "I can dynamically expand the environment, start with the 1 view I need, and add more tablets required to my needs".

DISCUSSION

Results

Our evaluation shows that search performance is not negatively impacted when moving a faceted search CMV system to multiple coordinated devices (RQ1). Multiple tablets even have advantages over large interactive systems, such as portability, extendibility and better focusability. In 1985, Bury et al. [5] reported that the use of multiple window systems results in more focused and accurate task performance than single window systems. Similarly, participants mentioned that multiple tablets would give them the possibility to pick up a tablet and perform more focussed work on individual facets.

A good overview can improve perceived satisfaction, but its effect on task performance is not clear [12]. Indeed, we found that the participants experienced a worse perception of overview on the tablets, which might also have caused their worse perception of search performance. However, neither seem to have affected the observed search performance. Distributing facet views across multiple devices does negatively impact user perception (RQ2).

Faceted search of large datasets through CMVs distributed on multiple devices can create a productive environment. While perceived overhead of multiple devices might fade with time, improvements can be made to how the user perceives the overview when exploring such a visualization. While the development of devices without bezels (e.g. the current Samsung Galaxy Edge) might not provide significant return on investment [30] regarding performance, it might be able to partially solve the perception problems related to the discontiguity across multiple devices.

Limitations

This study puts the emphasis on faceted search and limits the design of the application to four facets. Our goal was to create a realistic and ecologically valid system that should be manageable by most users. Increasing display size and resolution can improve user performance in rich-information environments [17]. The interactive tabletop benefits from a larger display area (42" versus 3 x 9.7" + 1 x 7.9"), while the iPads have a much higher pixel resolution (1920x1080 versus 4 x 2048x1536). The area size of the tabletop display (5115cm^2) can easily be filled with 10 regular iPads resulting in a large display containing 10 x 2048x1536 pixels, a resolution much higher and cheaper than 8K (3840x2160) Ultra HD screens. More views could create more overhead and negatively impact performance, with the difference between the two systems still to be explored.

CONCLUSION

Large interactive displays and surfaces are useful modalities for visualizing big multi-dimensional data sets [7, 16]. However, their required financial investment and large footprint makes deployment in everyday workspaces uncommon. As small touch devices become increasingly abundant, cheaper and more powerful, combining multiple tablets provides an alternative for the large single screen workspace [15, 19]. The mobile nature and flexible size of a multi-tablet setup means the system is deployable at many locations (including classrooms, on field trips, and even on public transportation), while its affordability makes it accessible to a larger audience.

This paper shows that for 4-facet visual search, spreading a CMV interface across tablets does not negatively impact the user's search performance (RQ1). However, a physical disconnection of the interface worsens the overview and performance perception (RQ2). Tablet solutions without bezels, guiding the user with visual indicators at the screen edges [11], and spatially aware devices [19] could potentially resolve these issues. A set of coordinated tablets can thus create an appropriate and convenient faceted search CMV alternative to large interactive surfaces.

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